THE GALACTIC CENTER MAGNETIC FIELD

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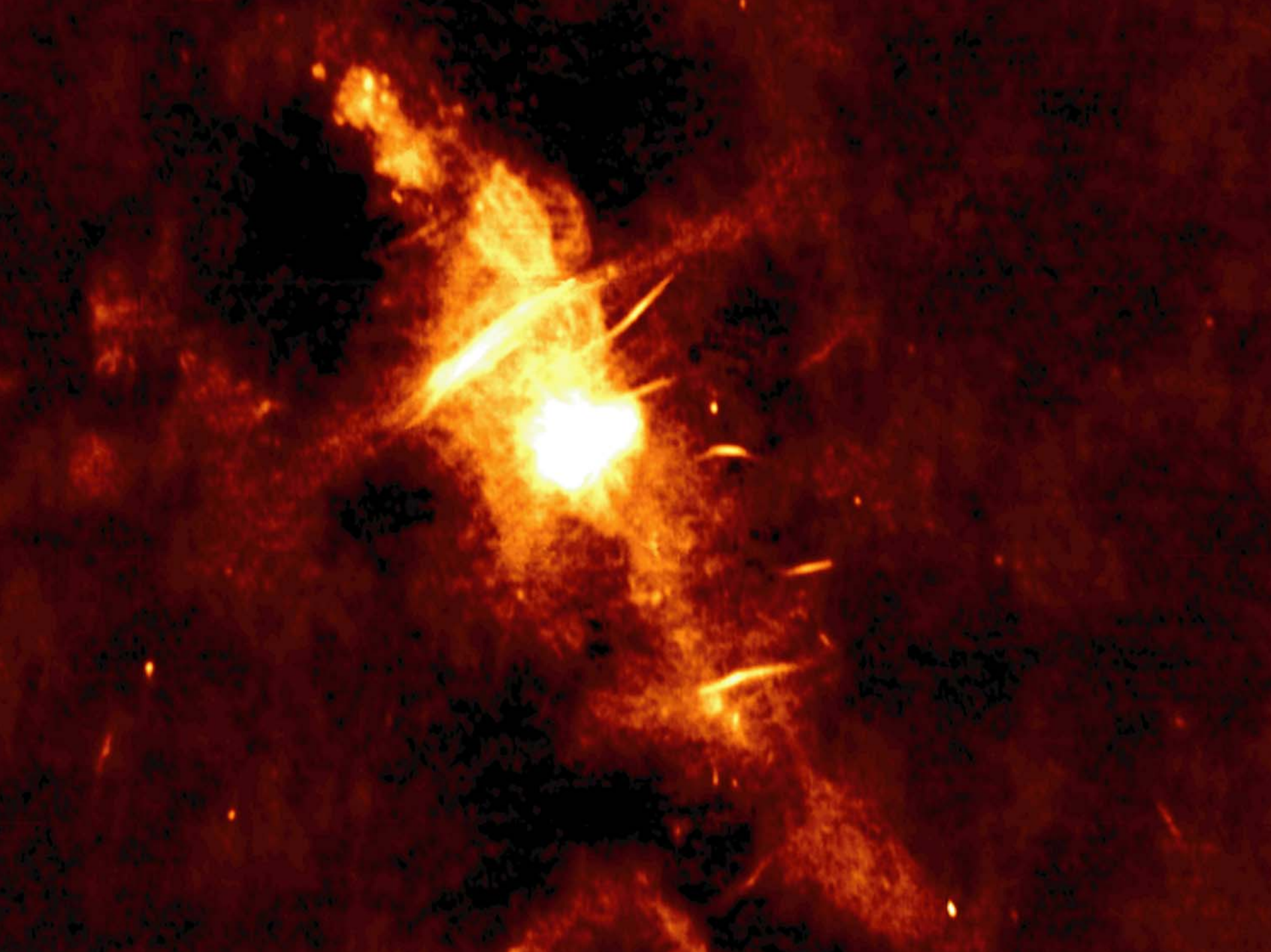
Glast Symposium Sept 2005

Outline

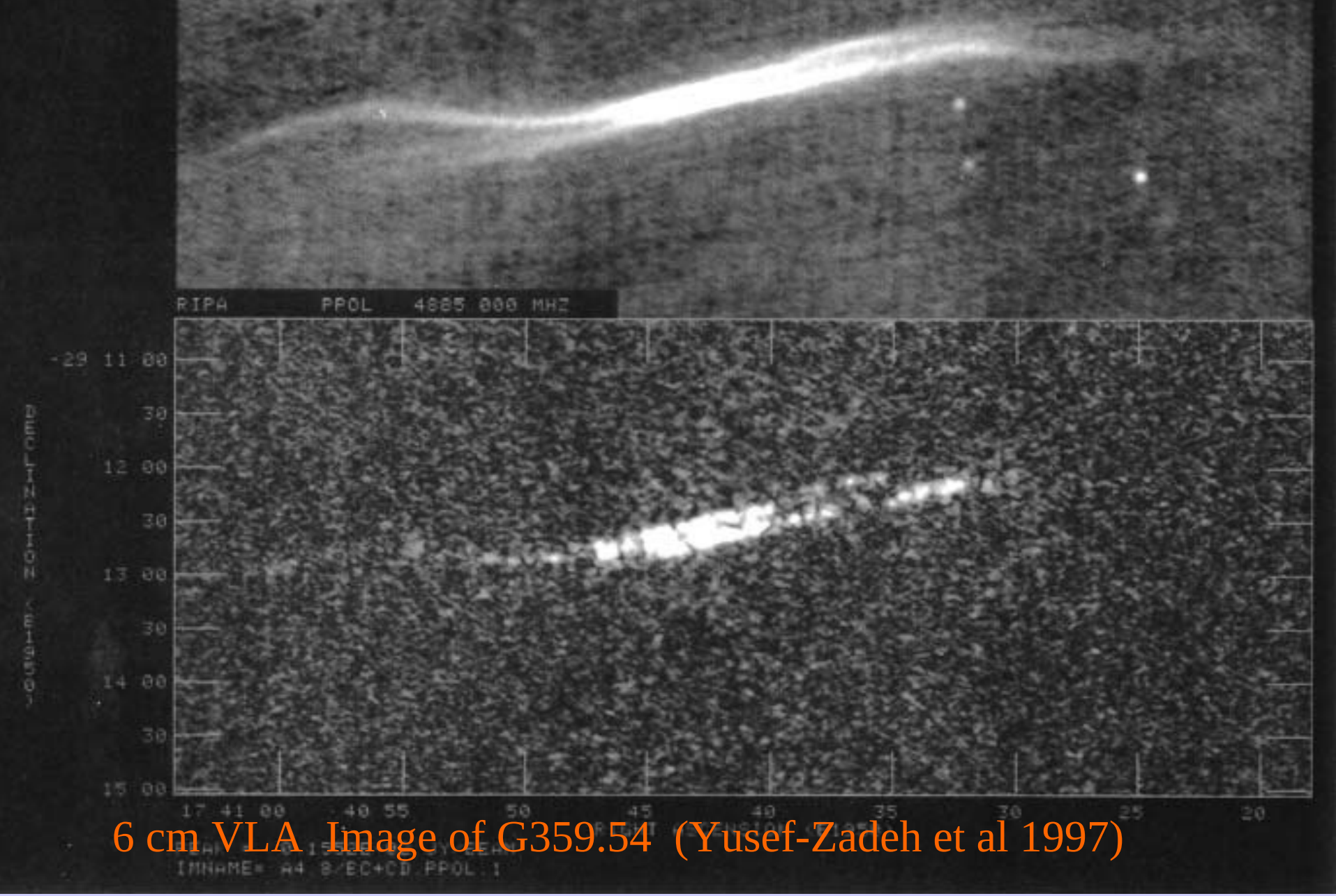
I. Describe magnetic structures in the GC

II. New interpretation based on low frequency wide-field imaging at 330 & 74 MHz

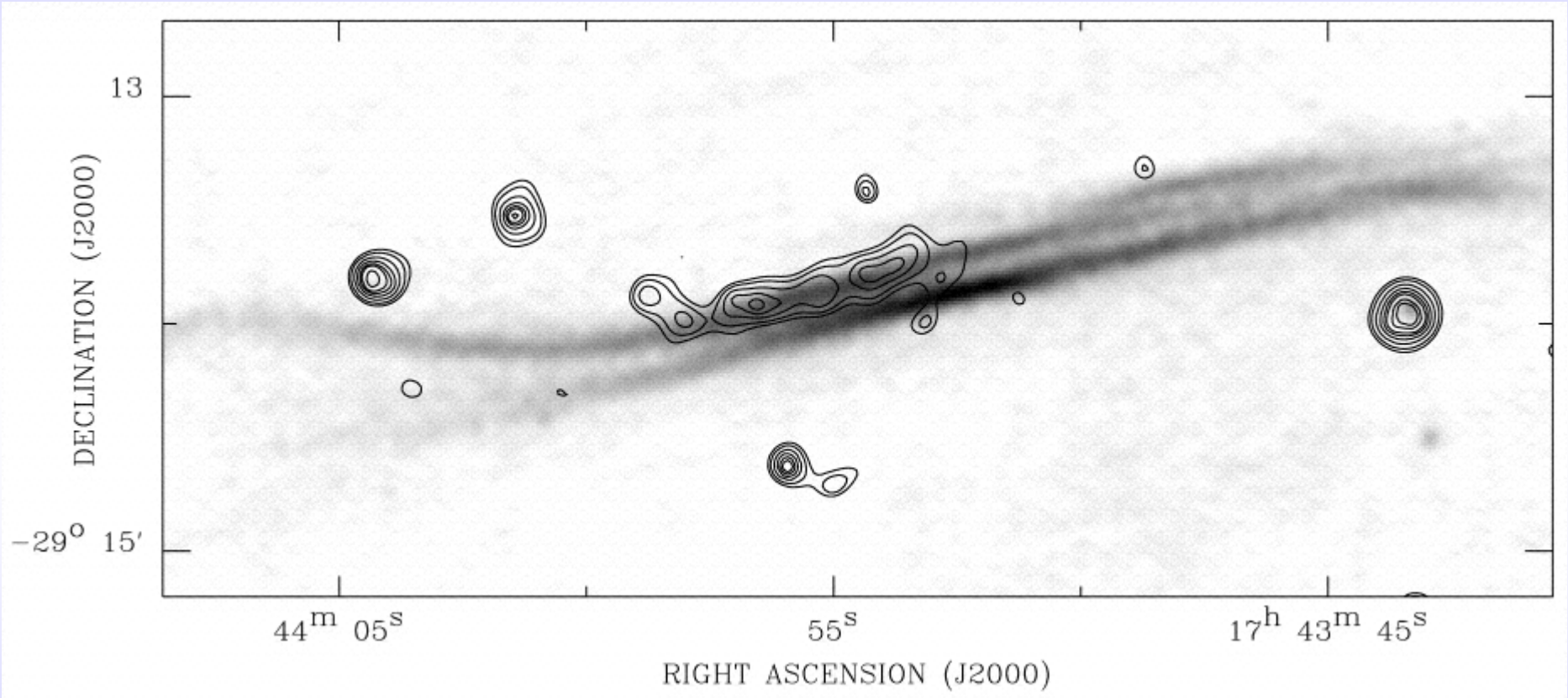
III. What is the GC cosmic-ray energy density?



20 cm VLA image (Lang, Morris & Echevarria 1999)



6 cm VLA Image of G359.54 (Yusef-Zadeh et al 1997)



2-9 keV Chandra Image - Lu, Wang & Lang 2003

Observed Characteristics

- Extreme length to width ratios (10-100)
- Highly polarized (30-70%)
- Strong (1 mG) magnetic fields aligned along their long axis
- Subfilamentation & braiding
- Associated with molecular clouds
- Peak intensity located near the geometric center
- Nonthermal spectra with curvature above 5 GHz

Questions theory must address

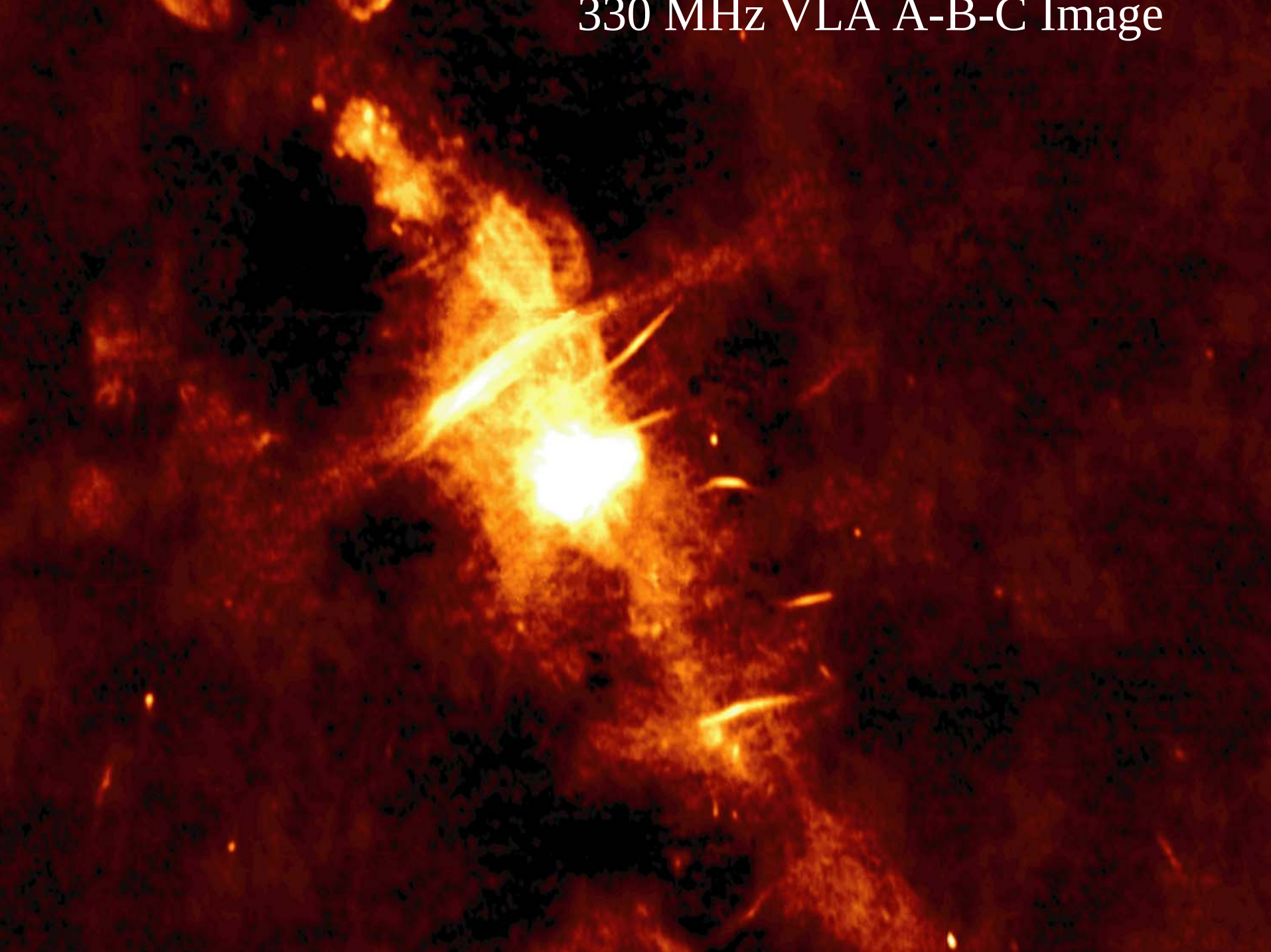
- Are the NTFs Global or local magnetic fields? Static or dynamic?
- What is the acceleration mechanism? Is it local or is the acceleration distributed along the length of the NTF?
- Why are they only observed at the Galactic Center?

Pervasive Field Model

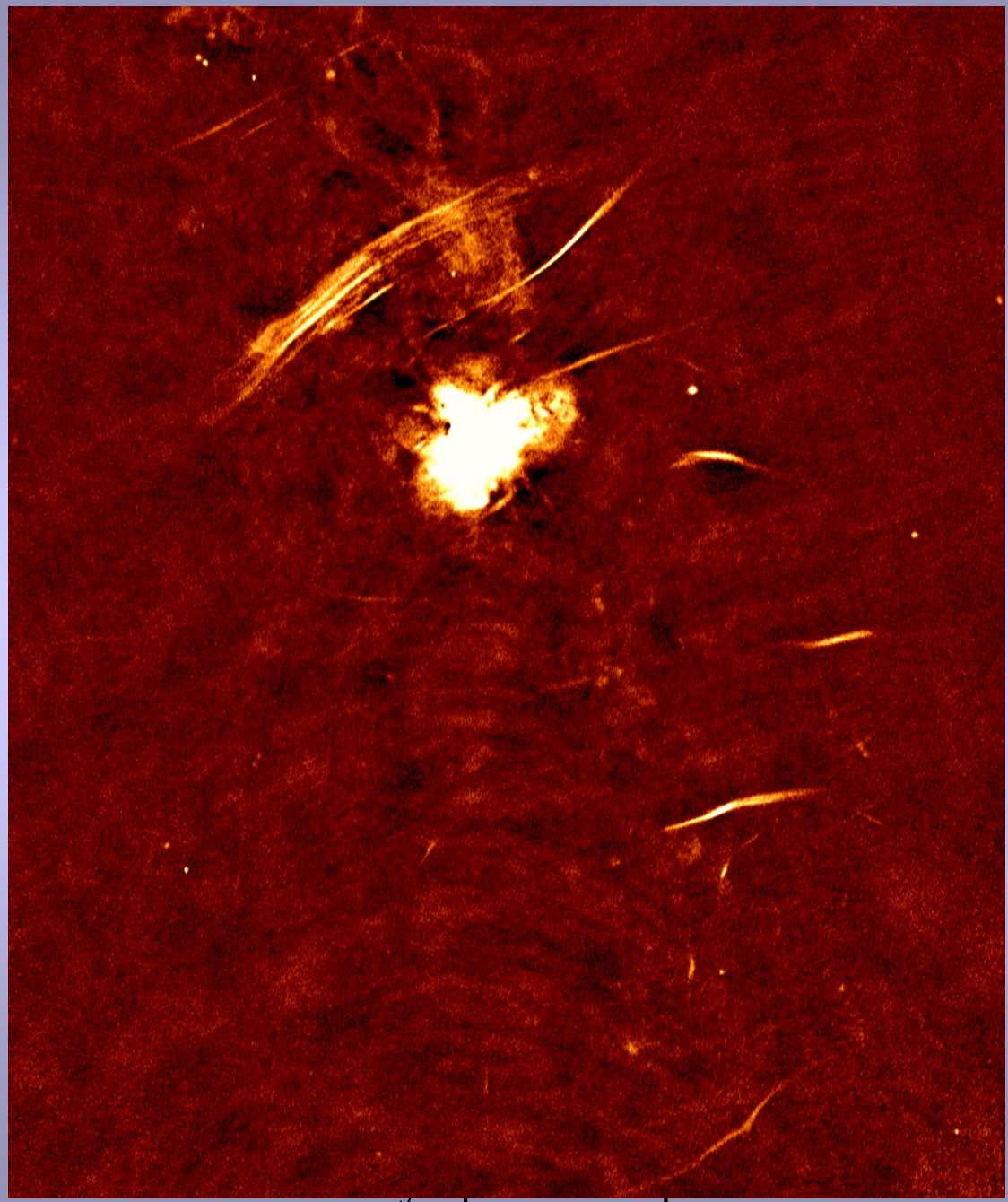
- Magnetic pressure exceeds the thermal pressure, therefore unless confined the filaments would expand on a timescale short compared to their synchrotron lifetime

- Filaments are locally illuminated flux tubes of a space-filling, globally organized field

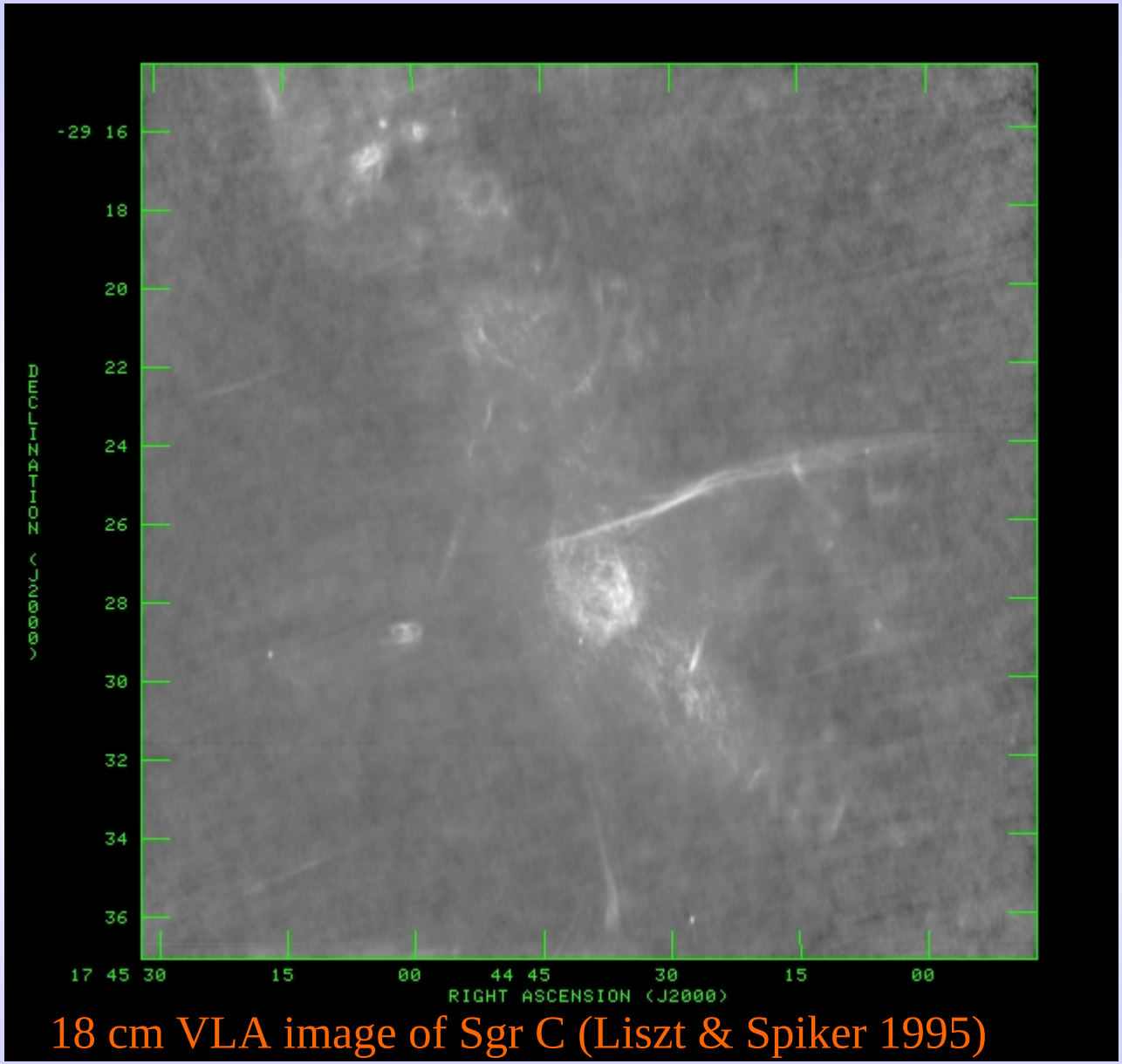
- Magnetic field energy required – $10^{54\text{-}55}$ ergs


330 MHz VLA A-B-C Image

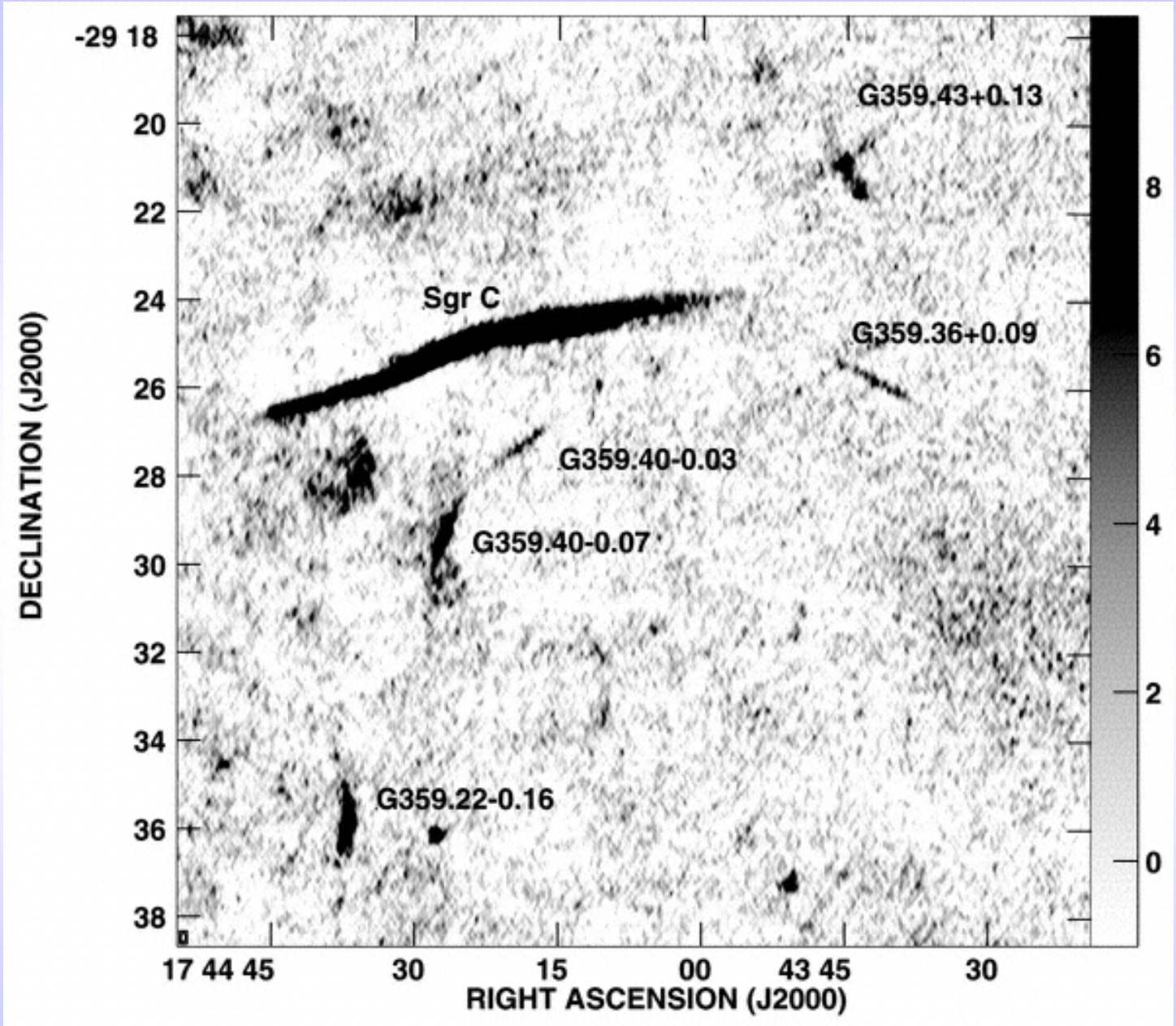
Nord et al 2004



330 MHz VLA A array



18 cm VLA image of Sgr C (Liszt & Spiker 1995)



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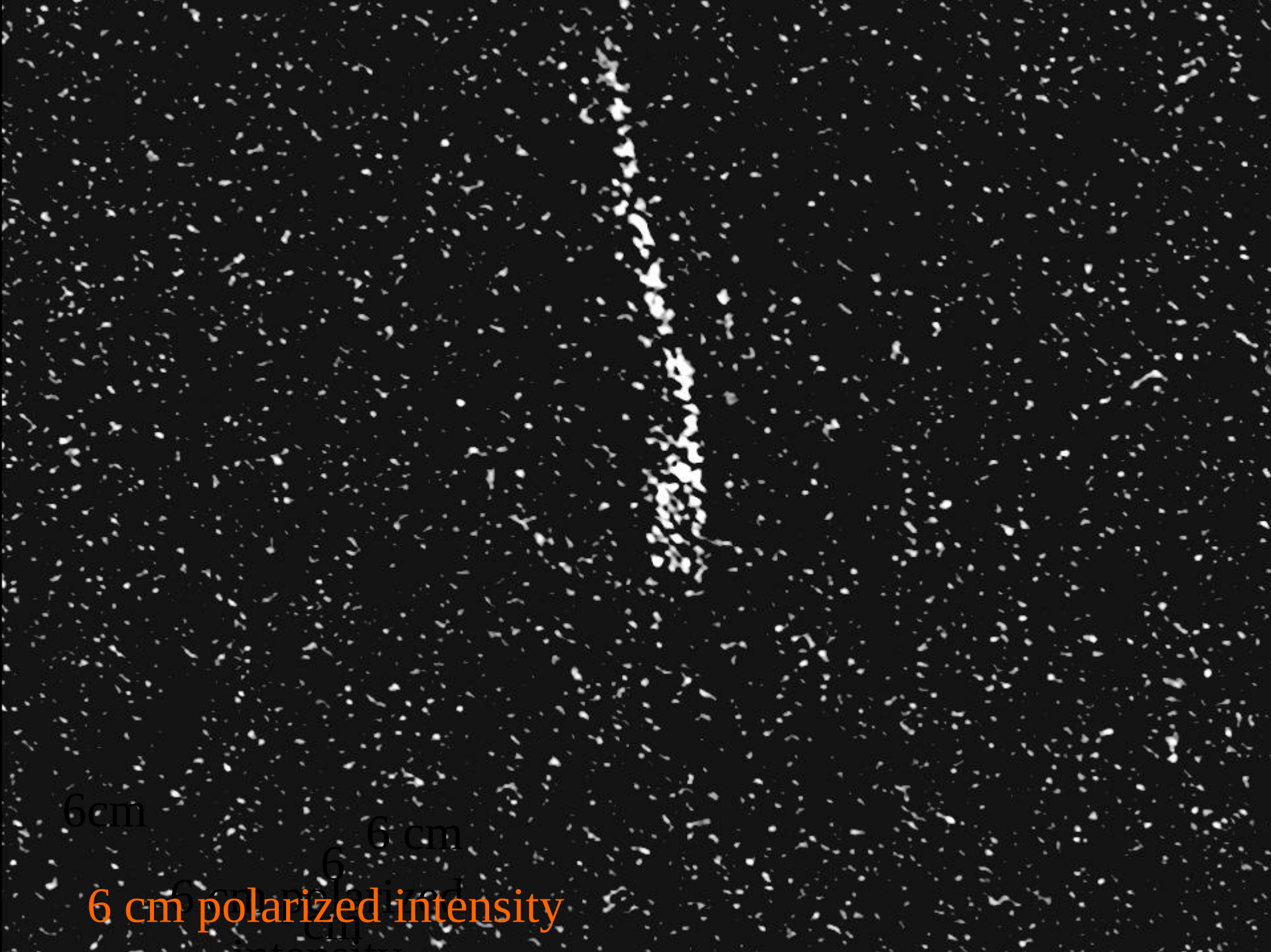
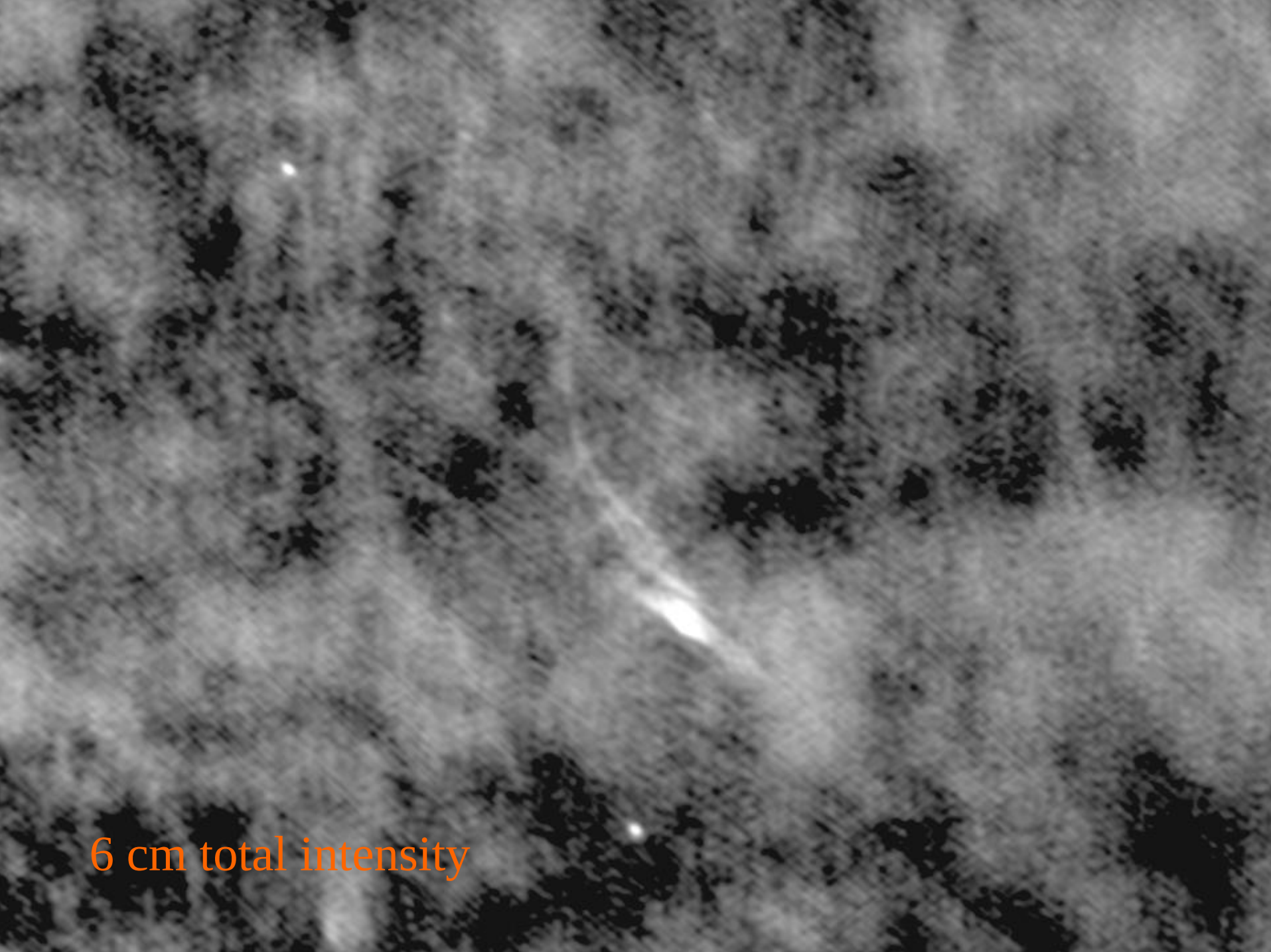
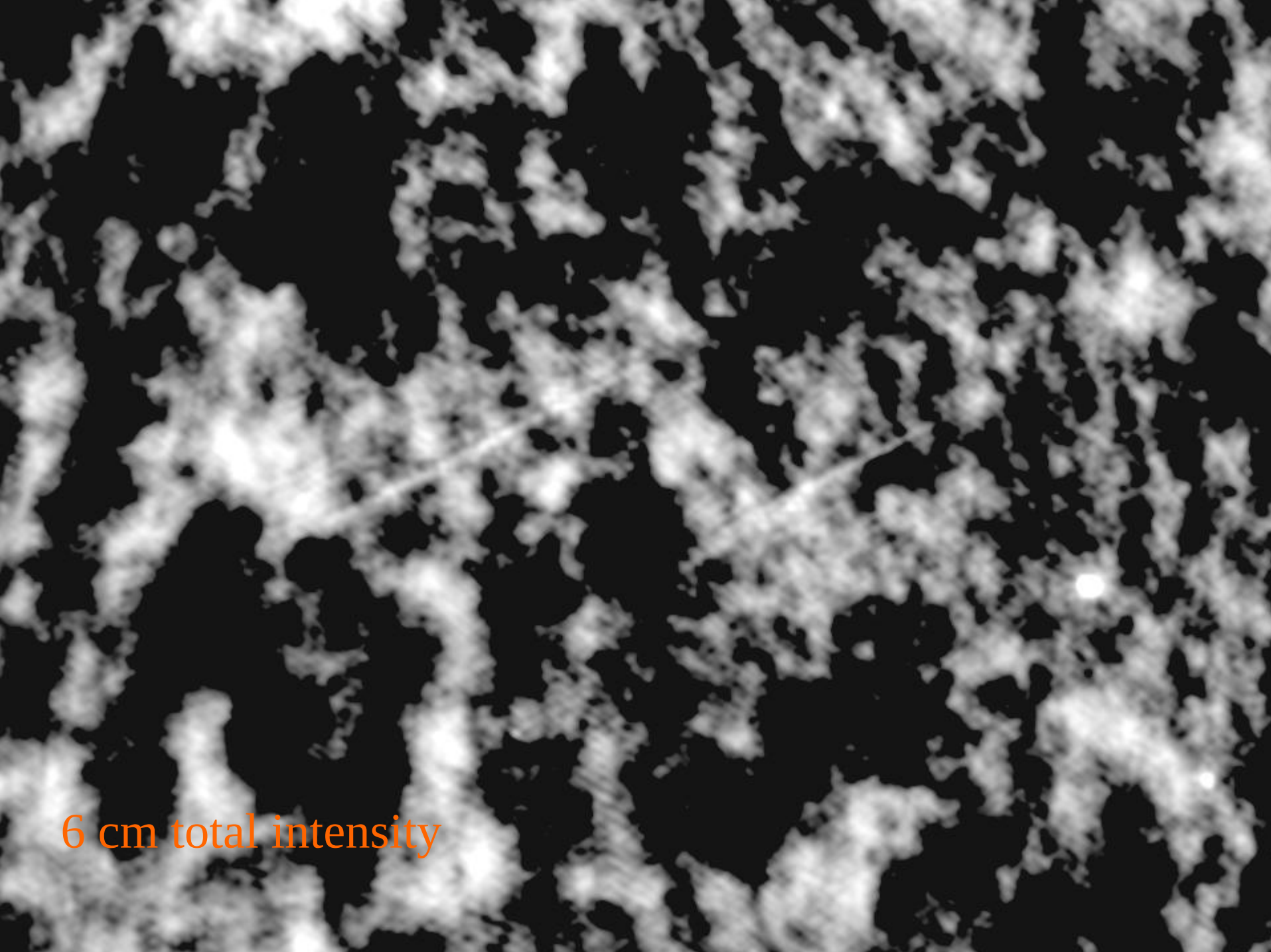
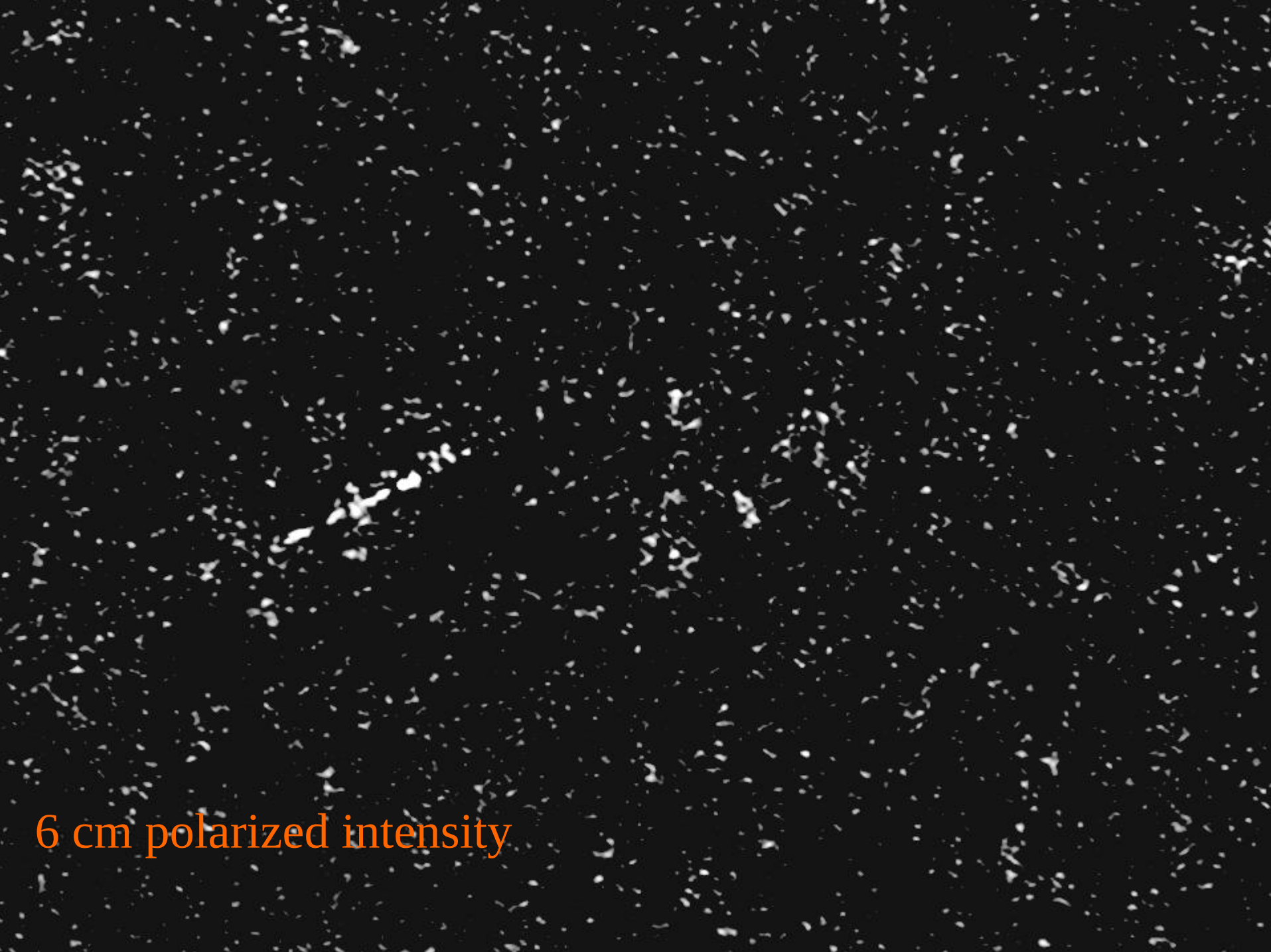
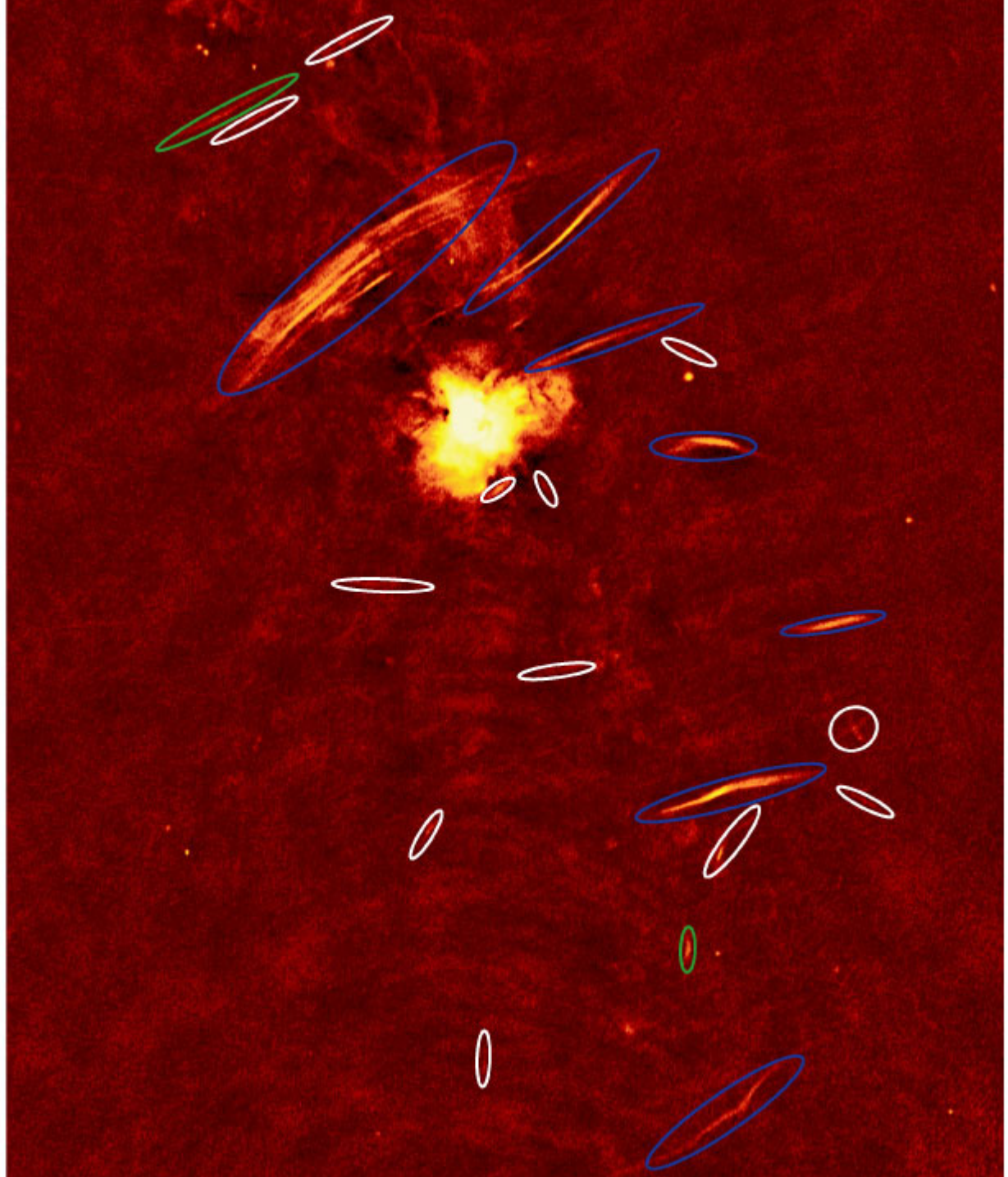
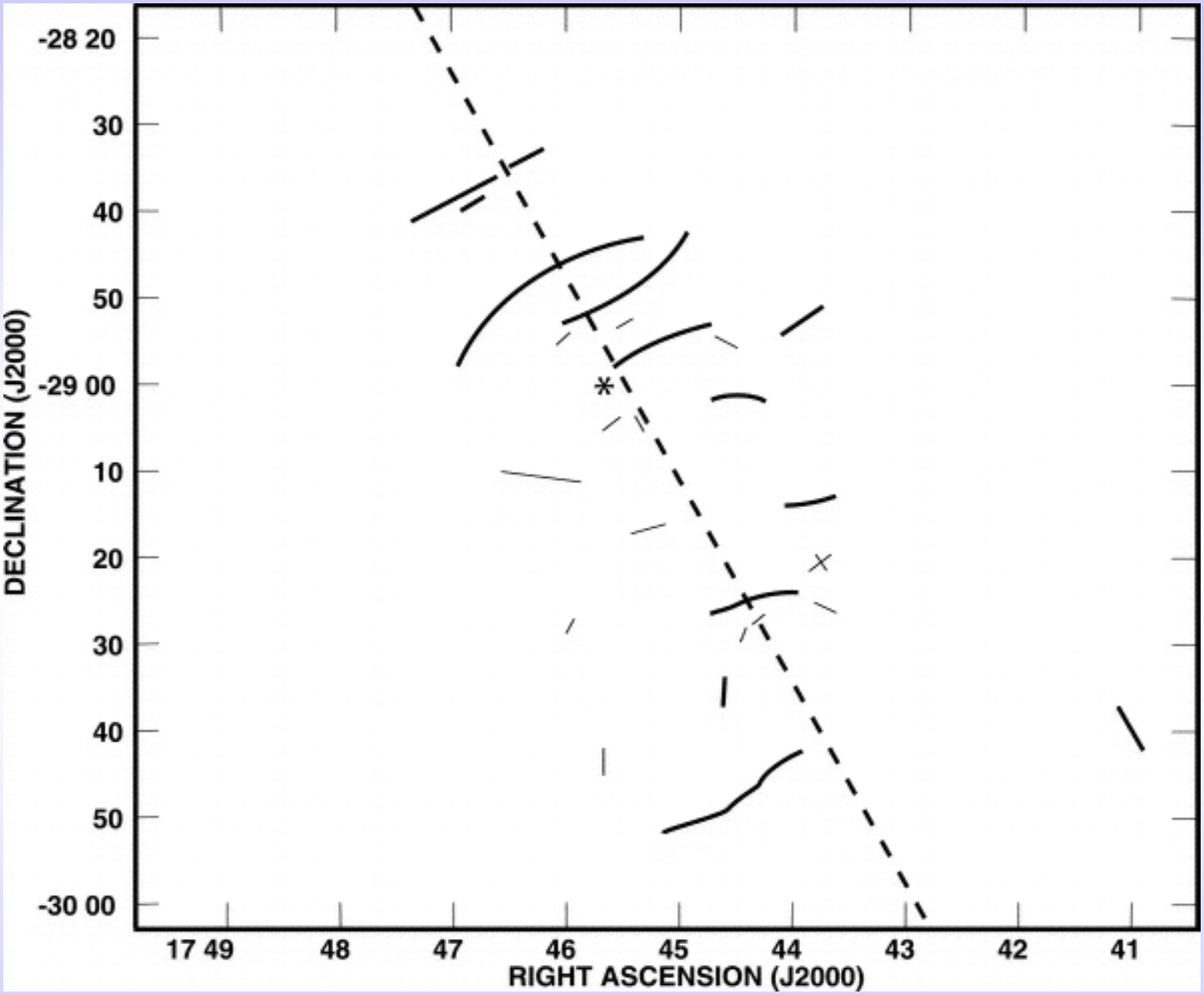

6cm
6 cm
6
6 cm polarized intensity


6 cm total intensity


6 cm total intensity

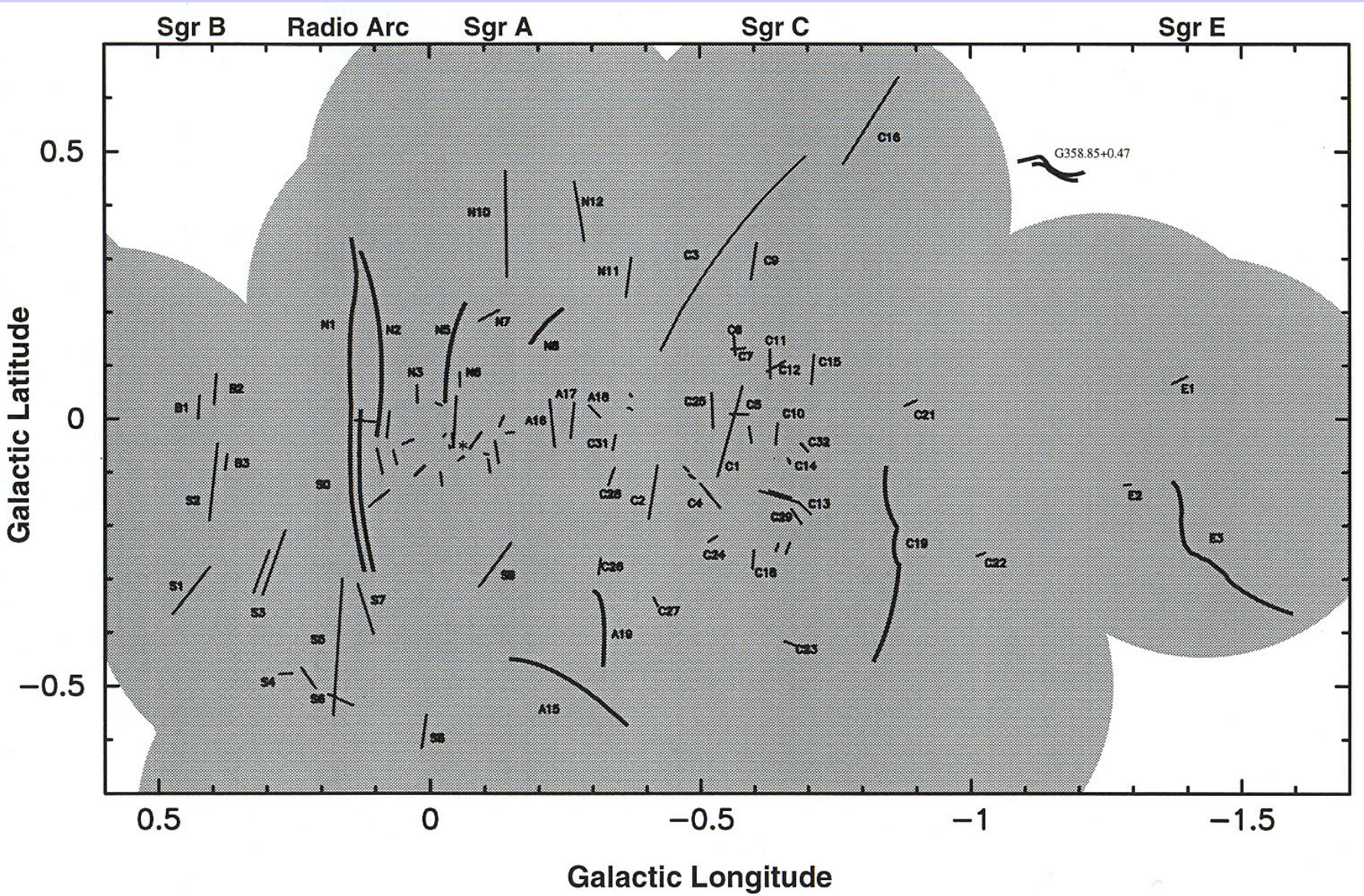

6 cm polarized intensity





LaRosa et al 2004 Glast Symposium Sept 2005

Yusef-Zadeh, Cotton & Hewitt 2004



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Summary of Known & Probable NTFs

- 10 confirmed NTFs perpendicular to the galactic plane
- 2 confirmed NTFs non perpendicular
- Several sources show NTF morphology with a variety of orientations to the galactic plane and other NTFs

$\Rightarrow$more complex magnetic field geometry

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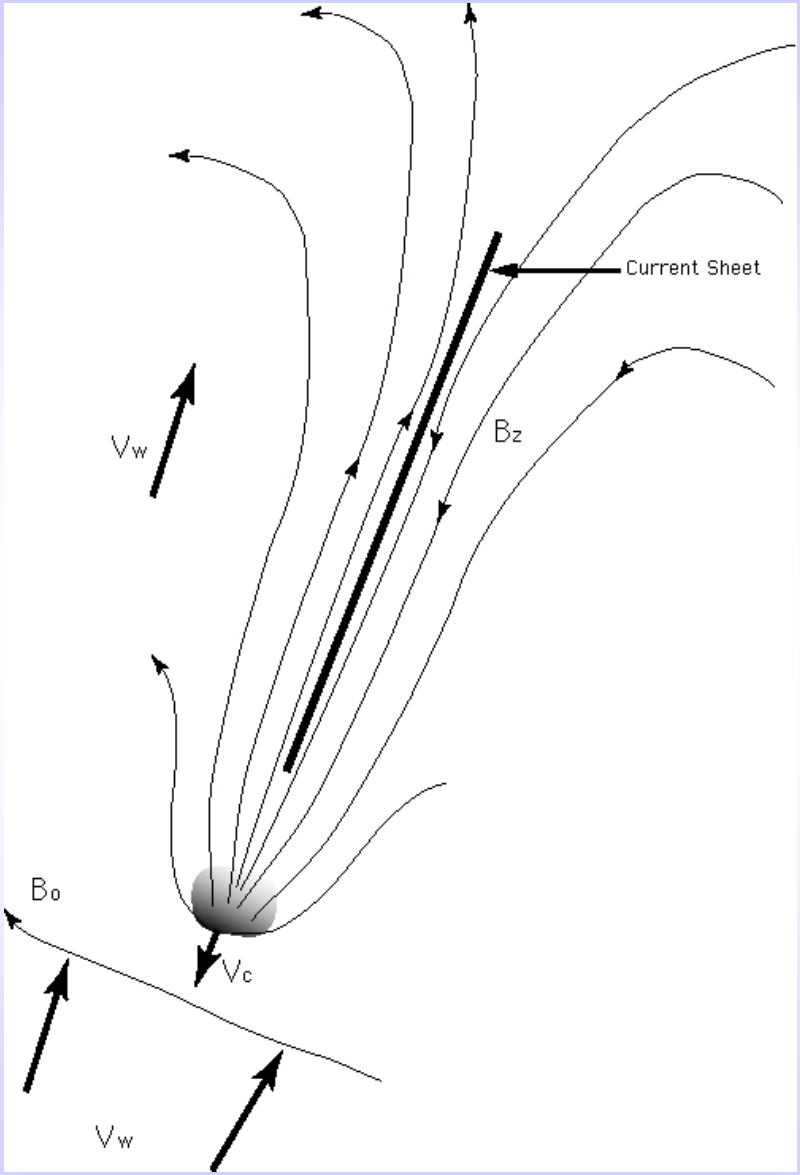
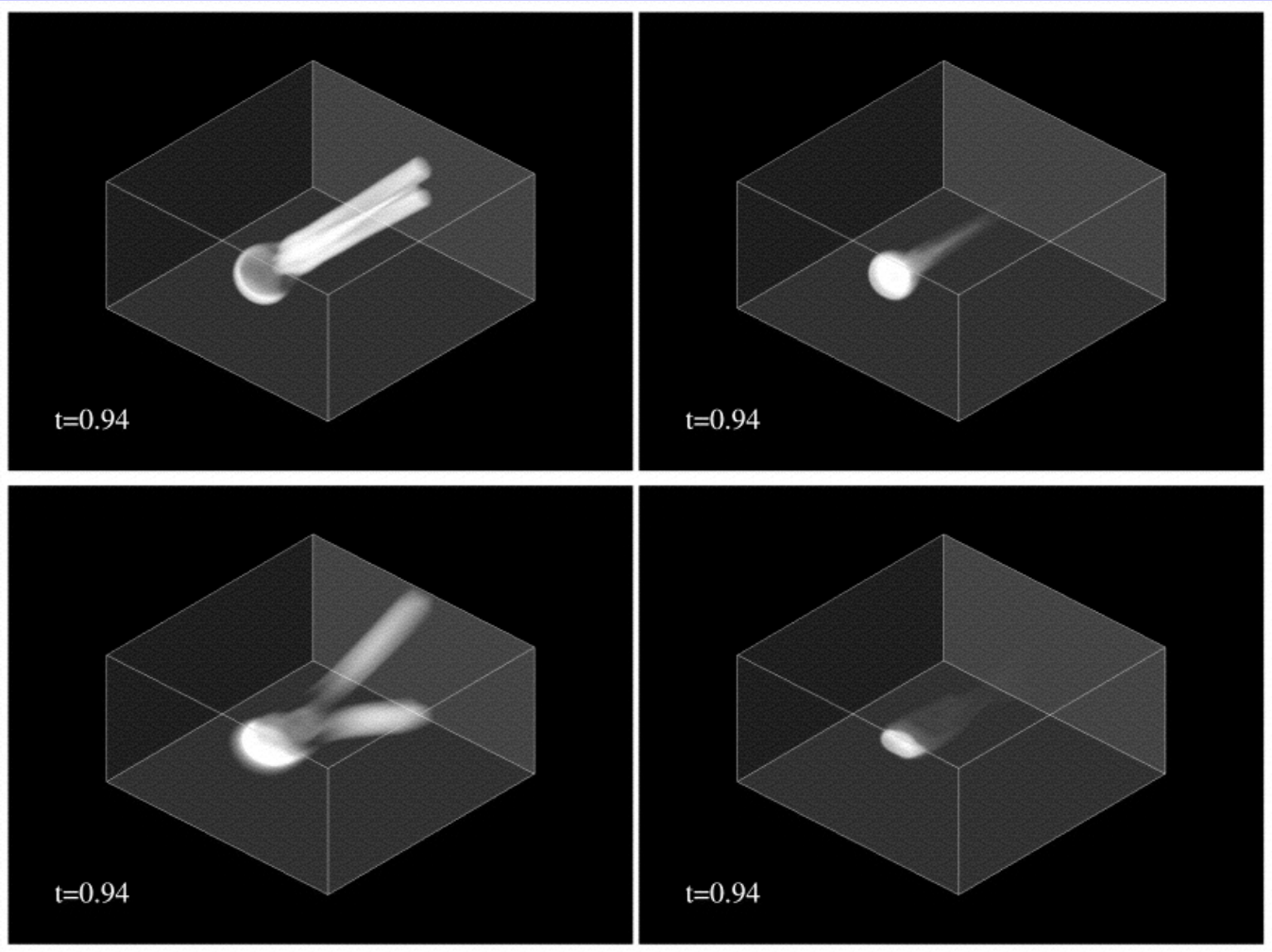


The Comet Model

Shore & LaRosa (1999)

β=100

β=4



Simulation of a cloud moving transverse to magnetic field – Gregori et al 2000

2-D Simulation of a Wake

- Initialized with small perturbations to insure unstable modes are naturally excited
- A linear code determines the fastest growing wavelength (KH instability) to normalize the scales for the full nonlinear calculation
- Exterior wind is 2000 km/s, n_∞=1 cm^{-3} , B_∞=10^{-2} mG, interior field 1 mG

Dahlburg et al 2002

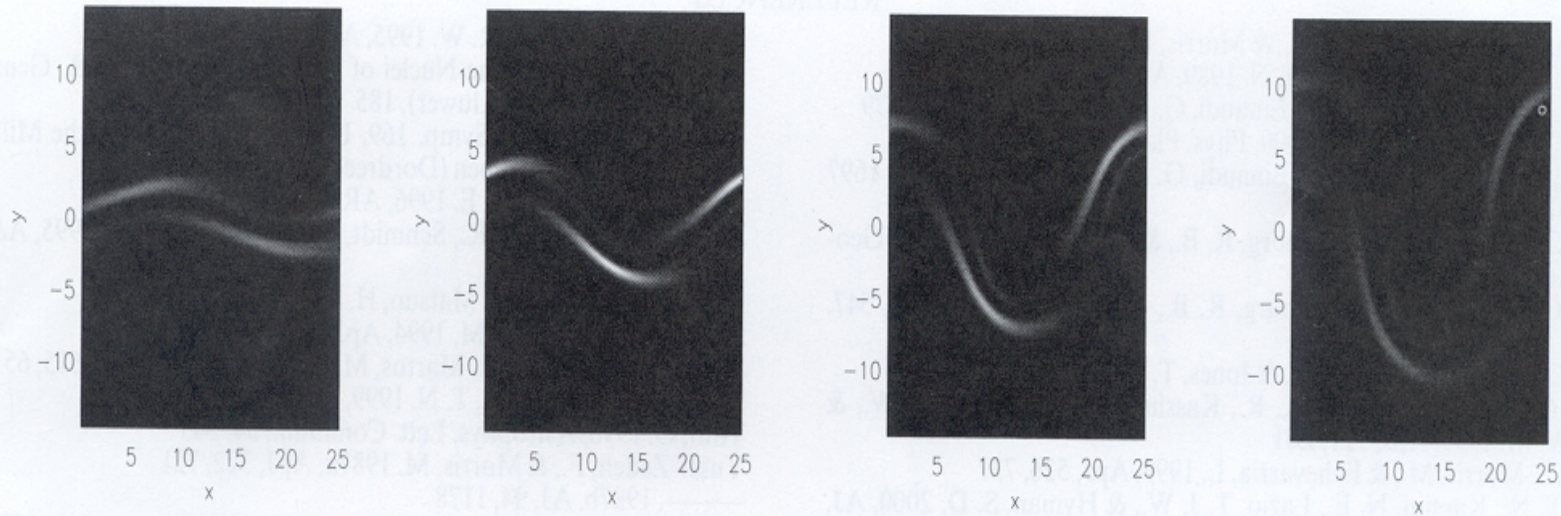
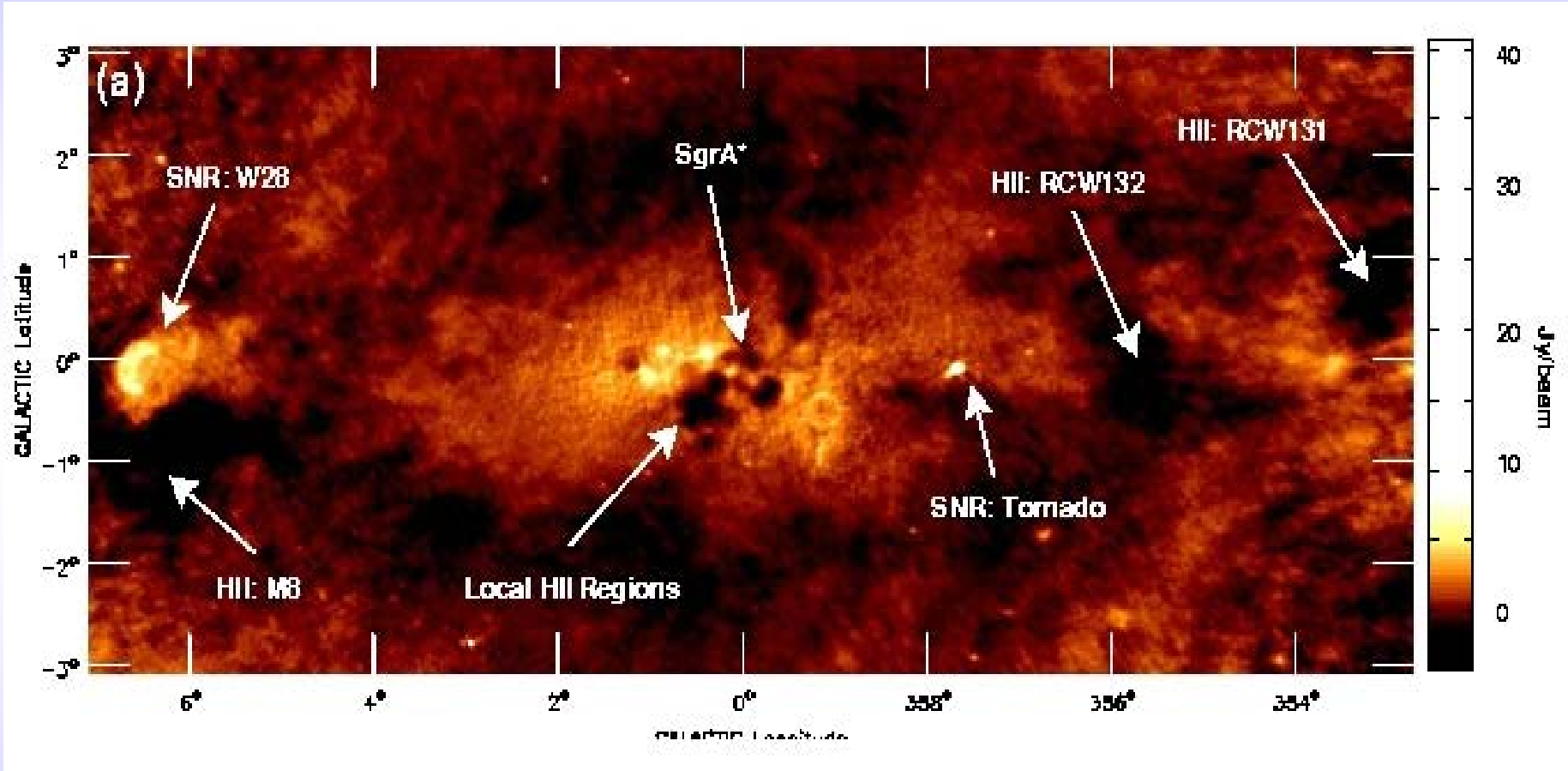
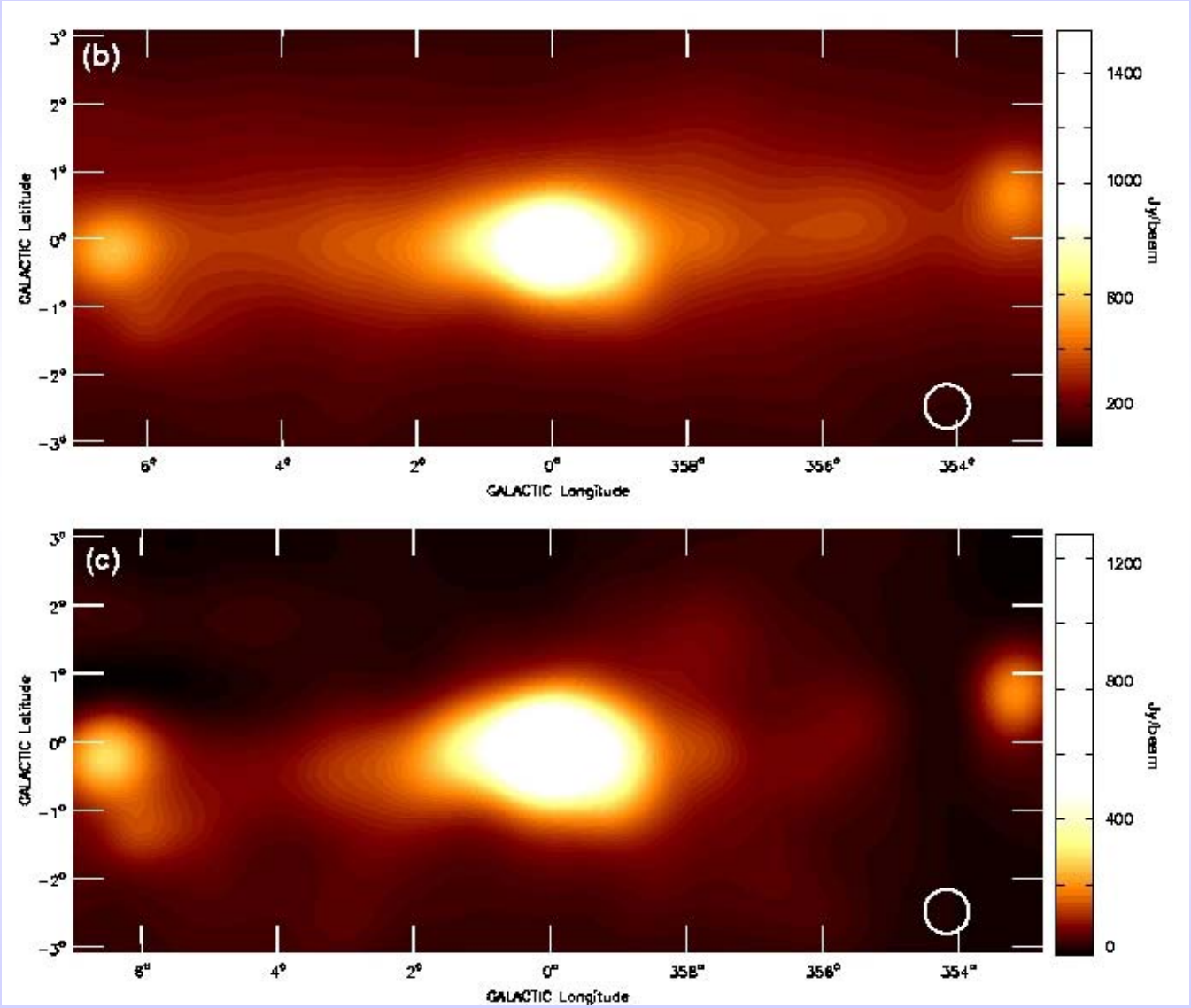


FIG. 6.—Filled contour plots of $|B|^2$. The gray scale is linear with white maximum and black minimum. The maximum amplification relative to the peak in Fig. 1 is about a factor of 3 in field strength. The times for each snapshot are 190, 220, 250, and 280 growth times corresponding to about 5, 20, 40, and 60 distance units (see text).

74 MHz VLA image





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Energy Requirements

- Total energy = $(\phi^{4/7} f^{3/7})$ x 10^{52} ergs

Particle energy = 1 $(\phi f)^{2/7}$ eV/cm^3

- B ≈ 6 $(\phi f)^{2/7}$ μG $\Rightarrow$ lifetime 5 x 10^7 yrs

$\Rightarrow$200 Sne over this lifetime, or 1 every 10^5 yrs

- Consistent with soft x-ray measurements

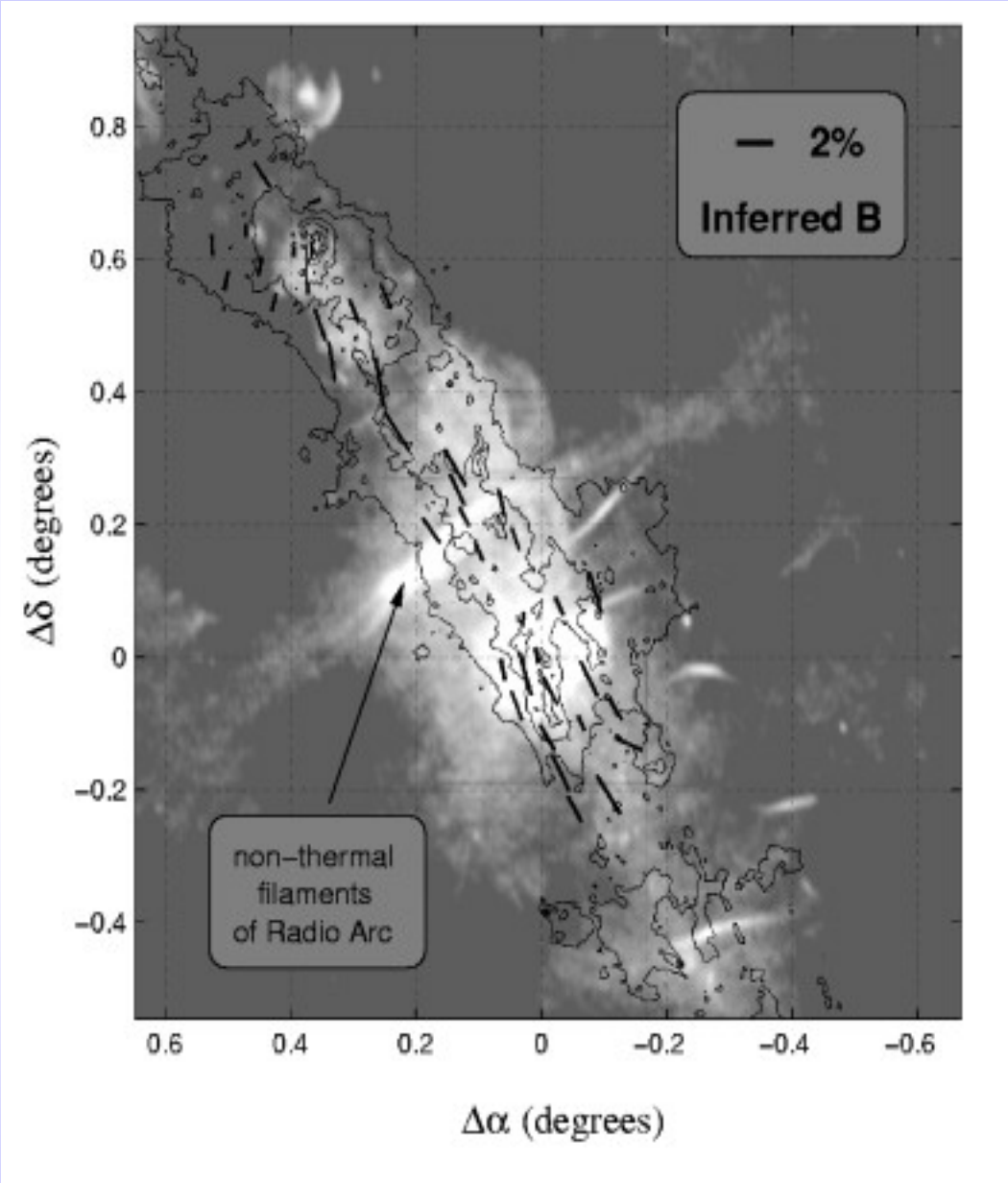
LaRosa et al 2005

What is the GC cosmic-ray energy density

- For just the inner 1.5 degrees the minimum energy analysis indicates B ≈ 11μG with a corresponding electron energy density of 7 eV/cm^3
- Local ISM is 0.2 eV/cm^3
- If B ≈ 1 mG observed intensity ⇒ 0.04 eV/cm^3
- Is the diffuse γ-ray emission consistent with either of these numbers?

What is the GC cosmic-ray energy density

- Gamma-ray observations (EGRET) indicate a cosmic ray energy density similar to the disk
- Ionization rate derived from H_3^+ is very high $\xi = 2\text{-}7 \times 10^{-15}\ s^{-1}\ cm^{-3}$ (Oka et al 2005)
- Searches for spallation products Li & B suggest upper limits of ≈ 10 times local ISM (Lubowich et al 1998)



Novak et al 2003

Roy 2003

$RM \propto \int n_e B_{||} dl$

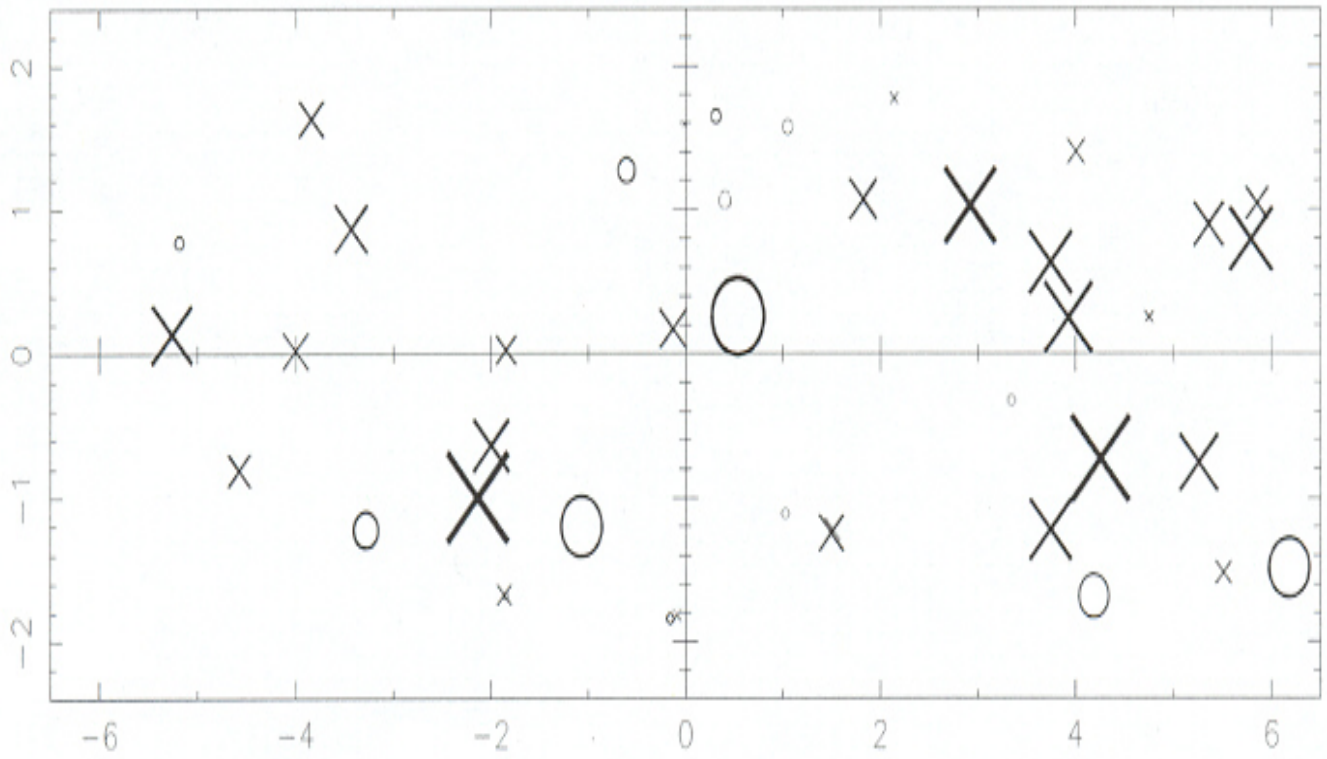


Figure 5. The plot of the RM towards various sources as a function of the Galactic longitude and latitude. The cross symbol (×) indicates positive RM and the circle (○) negative RMs, where the symbol size increases linearly with |RM|.

Conclusions:

- Confirmed population of NTFs is difficult to reconcile with a globally ordered field

$\Rightarrow$ *complex field geometry*

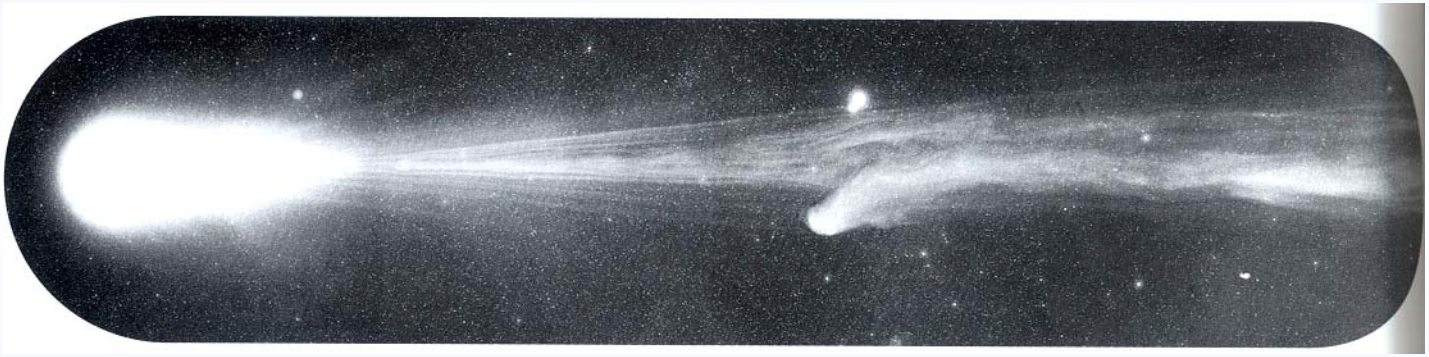
- NTFs could be generated by dynamically

$\Rightarrow$ *strong pervasive field not required*

- Low frequency, diffuse nonthermal emission

  $\Rightarrow$ *weak global magnetic field*

- Cosmic-ray energy density needed



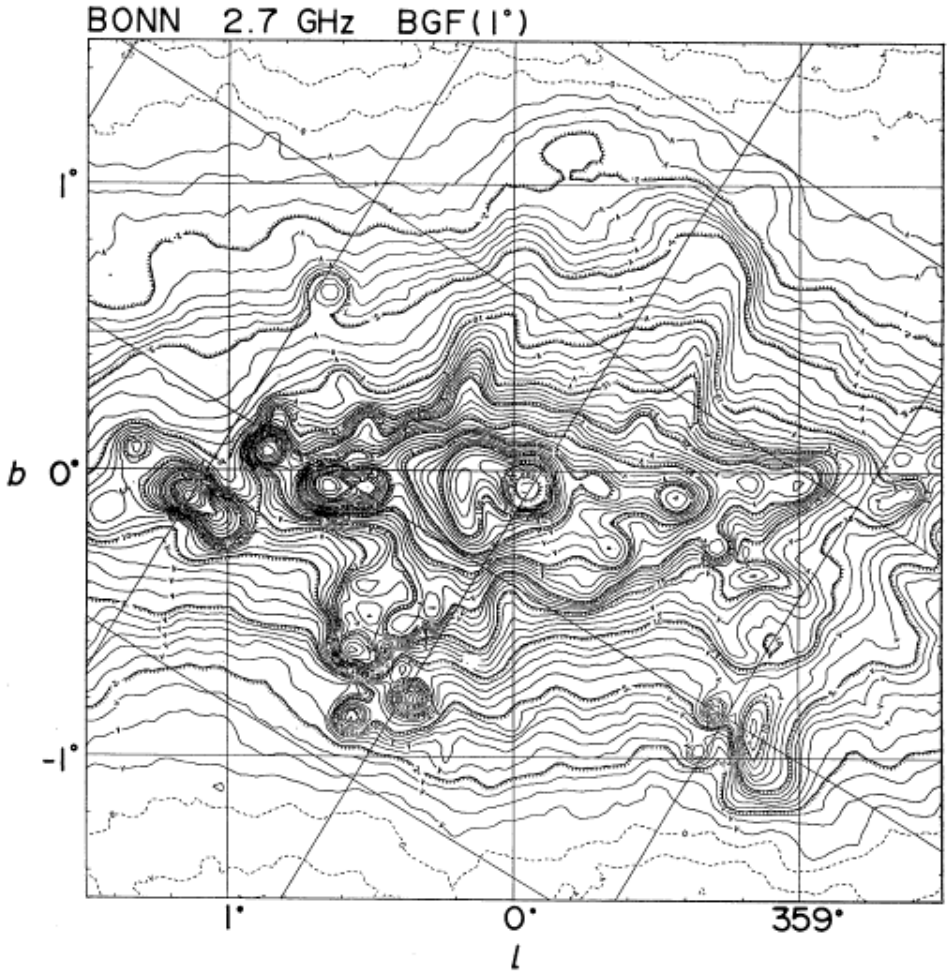
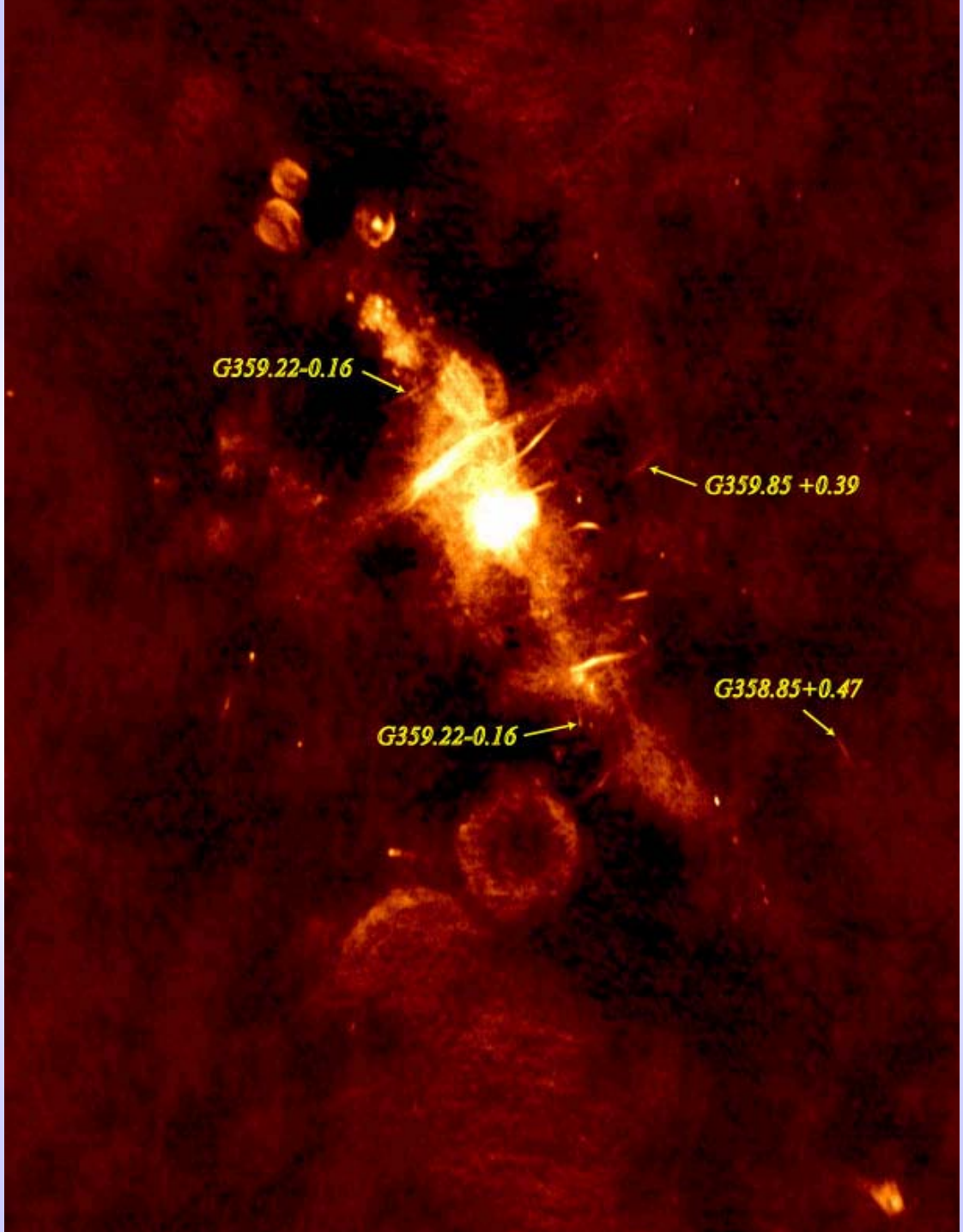
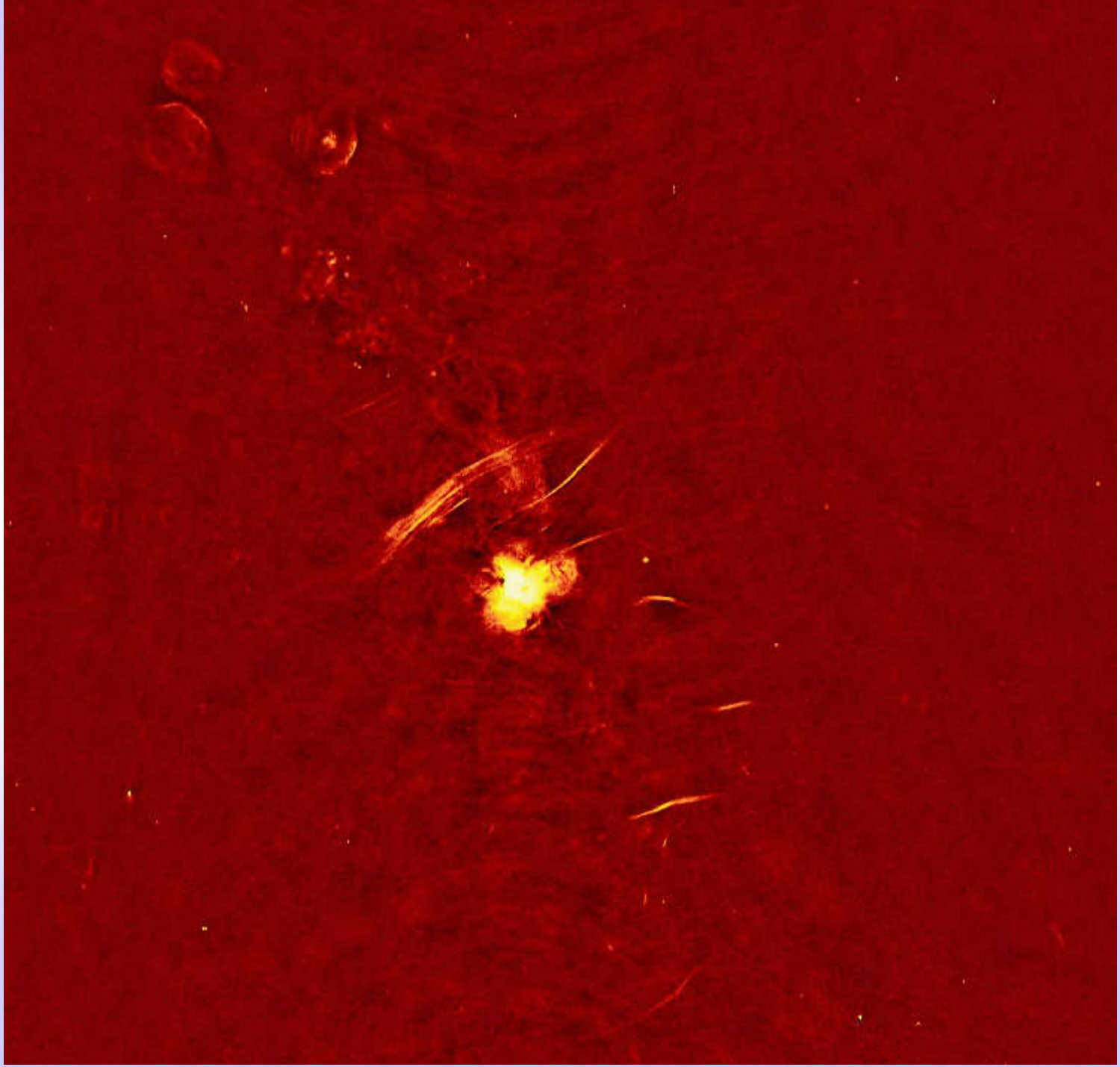
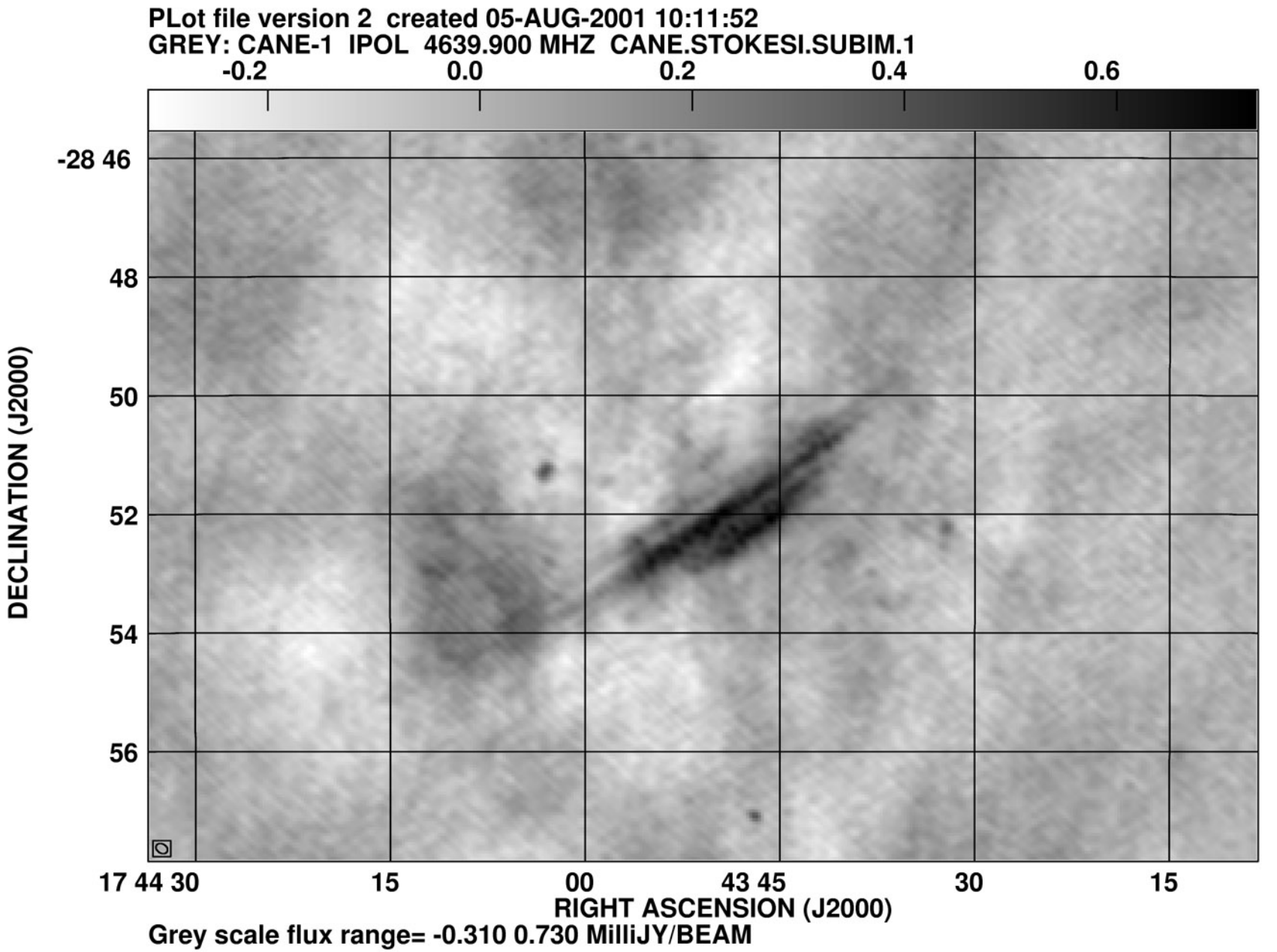


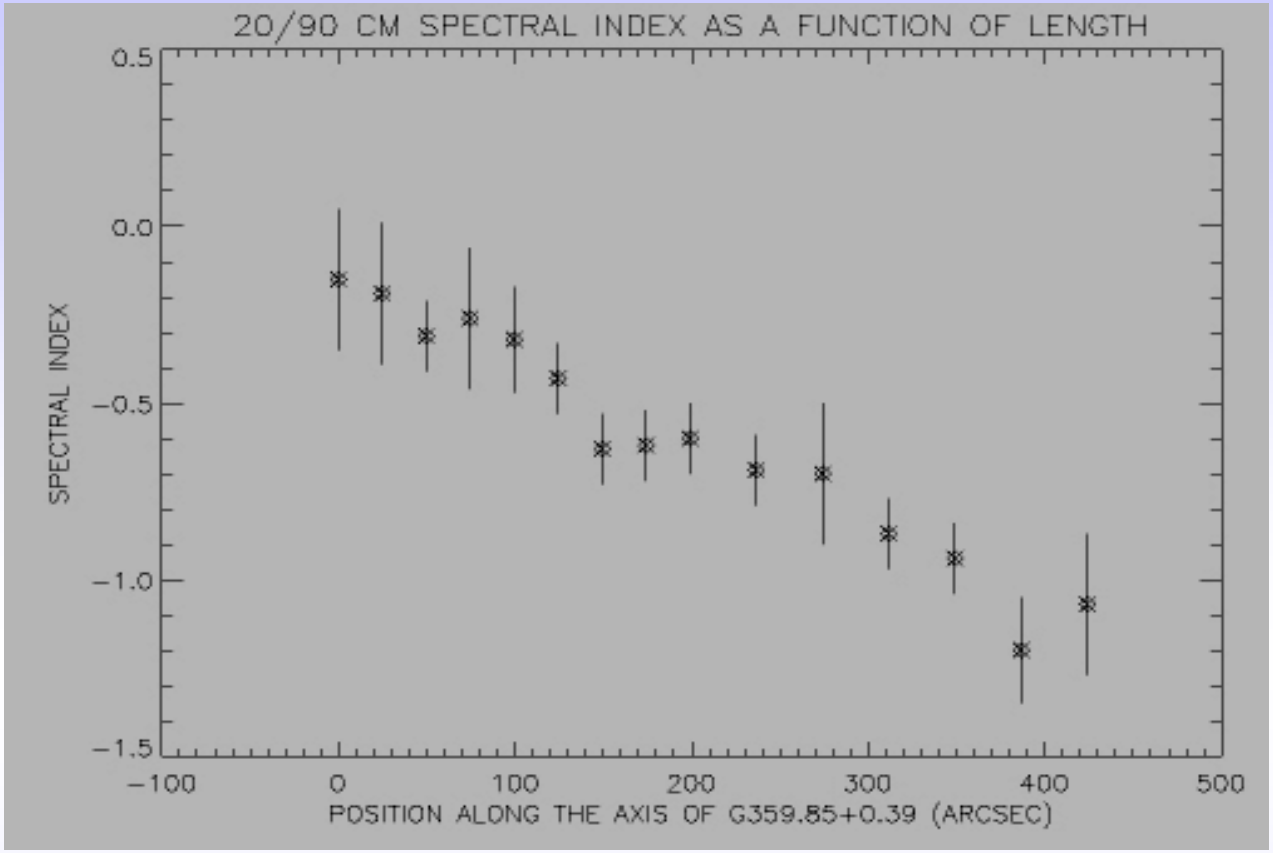
Fig. 4. A BGF map same as figure 1 but at 2.7 GHz from the Bonn survey (Reich et al. 1984). The HPBW of the map is 4.'3. A BGF has been applied with the same filtering beam size of 1.°0 as in figure 1. The unit of the contour numbers is 10^{-21} W m^{-2} sr^{-1} Hz^{-1}.


G359.22-0.16
G359.85 +0.39
G358.85+0.47
G359.22-0.16





6 cm VLA CnD image of G359.85 + 0.39



Best explanation is a curved electron energy spectrum radiating in a diverging magnetic field – LaRosa, Lazio & Kassim (2001)

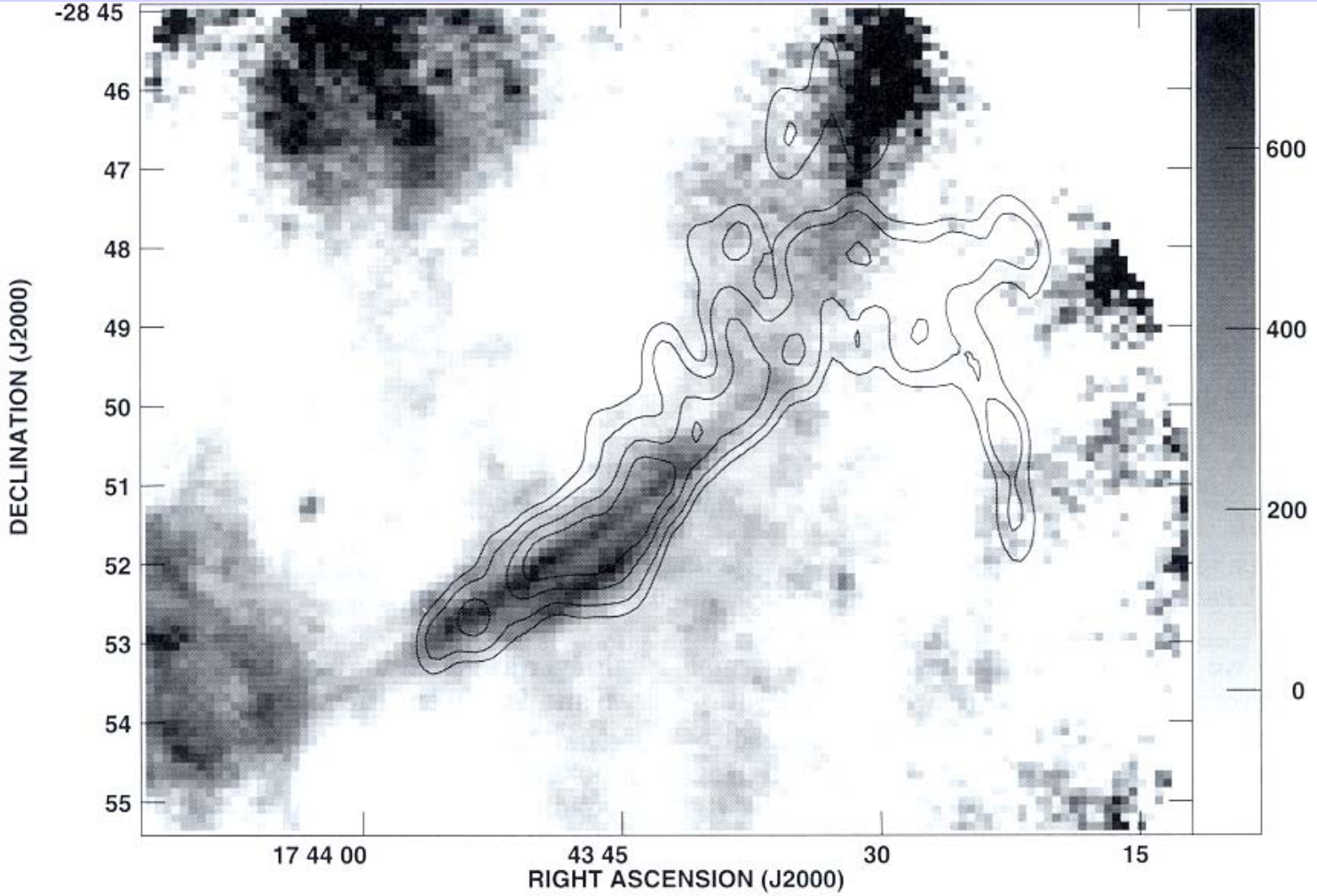


FIG. 6.—Gray-scale of 6 cm emission (Fig. 4) overlaid on contours of the 90 cm emission (Fig. 1)